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(54) **INTEGRATED SENSOR AND MAGNETIC FIELD CONCENTRATOR DEVICES**

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This patent is subject to a terminal disclaimer.

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G01P 3/487	(2006.01)
G01R 33/00	(2006.01)
H01L 27/22	(2006.01)

(52) **U.S. Cl.**

CPC ***G01P 3/487*** (2013.01); ***G01R 33/0005*** (2013.01); ***H01L 27/22*** (2013.01)

(58) **Field of Classification Search**

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USPC 324/252
See application file for complete search history.

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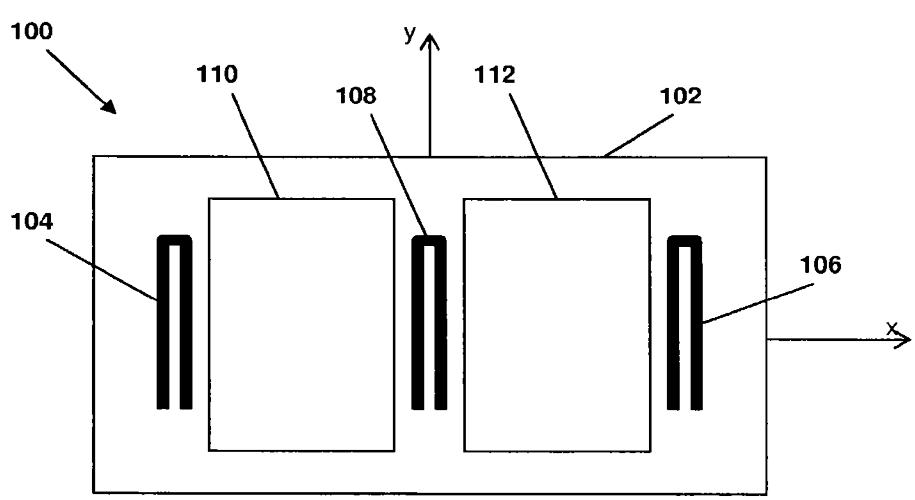
(57) **ABSTRACT**

Embodiments relate to integrated sensor and magnetic concentrator devices and methods. In one embodiment, an integrated sensor and magnetic field concentrator device comprises a sensor device comprising at least two xMR sensor elements spaced apart from each other on a surface of a die to define a first gap of about 5 millimeters (mm) or less; and a magnetic field concentrator disposed in the first gap and configured to guide magnetic flux from an external source in a direction perpendicular to the at least two xMR sensor elements.

17 Claims, 2 Drawing Sheets



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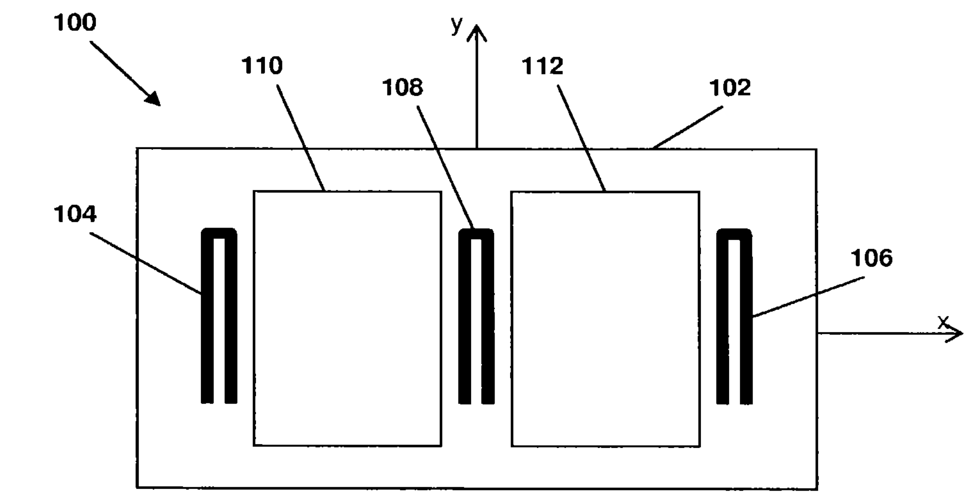
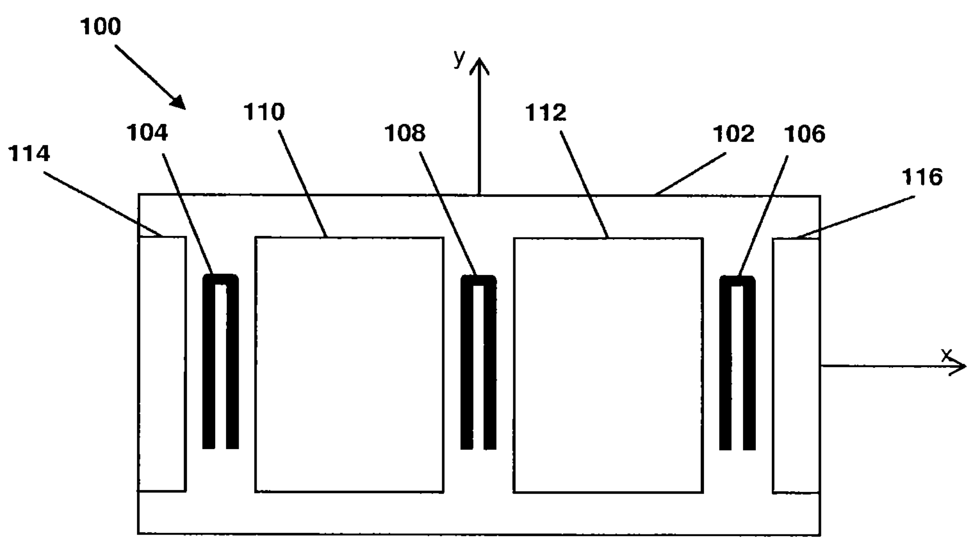

100
110
108
112
102
104
106
y
x

FIG. 1


100
114
104
110
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102
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116
y
x

FIG. 2

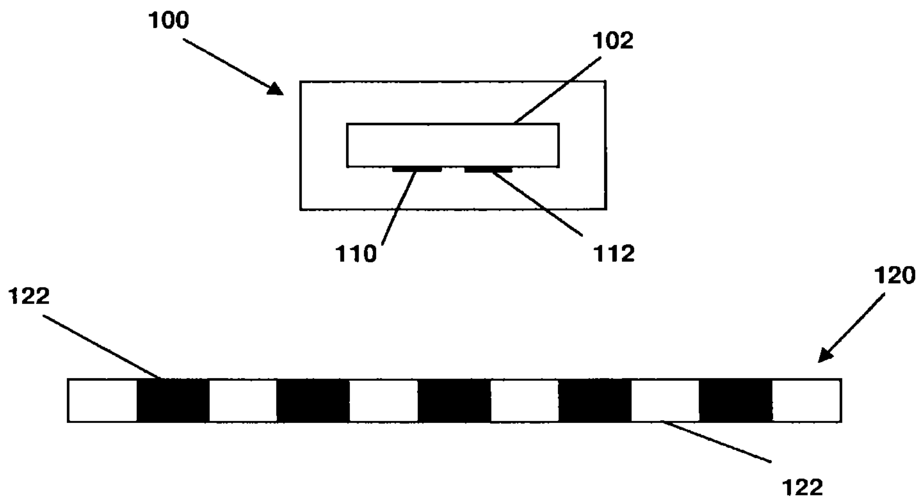

FIG. 3

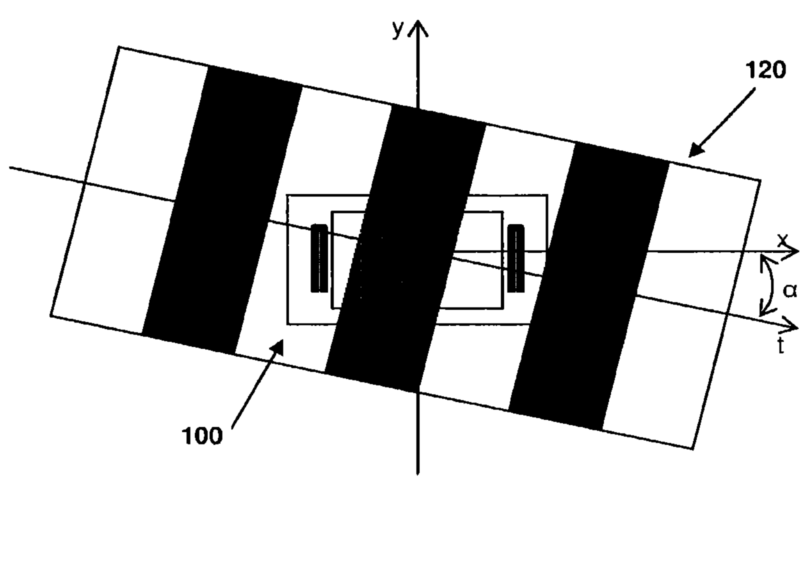

FIG. 4

INTEGRATED SENSOR AND MAGNETIC FIELD CONCENTRATOR DEVICES

RELATED APPLICATION

This application is a continuation of application Ser. No. 12/169,746 filed Jul. 9, 2008, which is hereby fully incorporated herein by reference.

BACKGROUND

To detect the speed and direction of a rotating wheel or other object, it is common practice to attach a magnetically polarized ring to the wheel and position a magnetic field sensor nearby. As the alternating magnetic poles (north, south, north, south, etc.) pass by during rotation, the field sensor detects and converts the pole-sequence into a pulsed output voltage. The rotational speed of the wheel can then be derived by counting the pulses per second.

In order to obtain fine resolution, many poles on the ring are desired. Unfortunately, the magnetic field of the poles does not extend far beyond the ring itself; in fact, it decreases exponentially with the distance from the ring. The field typically disappears almost entirely at a distance that is about two to three pole-pitches away from the ring, where the pole-pitch is the distance between the centers of two adjacent poles on the ring.

Because of assembly tolerances, the distance between the field sensor and the pole-ring may vary. Thus, there is a need for a magnetic field sensor system that is compatible with both small (e.g., about 0.5 mm) and large distances (e.g., up to about several millimeters), in other words a magnetic field sensor that is sensitive to small magnetic fields.

SUMMARY

Embodiments relate to integrated sensor and magnetic concentrator devices and methods. In one embodiment, an integrated sensor and magnetic field concentrator device comprises a sensor device comprising at least two xMR sensor elements spaced apart from each other on a surface of a die to define a first gap of about 5 millimeters (mm) or less; and a magnetic field concentrator disposed in the first gap and configured to guide magnetic flux from an external source in a direction perpendicular to the at least two xMR sensor elements.

In another embodiment, a method comprises providing an integrated sensor and magnetic field concentrator device, the sensor comprising first and second xMR sensor elements spaced apart by a gap of about 5 millimeters (mm) or less, and the magnetic field concentrator disposed in the gap; exposing the device to a magnetic field; and guiding a magnetic flux related to the magnetic field perpendicularly to the sensor by the magnetic field concentrator.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be more completely understood from the following detailed description of various embodiments in connection with the accompanying drawings, in which:

FIG. **1** is a top view of a block diagram of a sensor according to an embodiment.

FIG. **2** is a top view of a block diagram of a sensor according to an embodiment.

FIG. **3** is a side view of a block diagram of a sensor and a pole wheel according to an embodiment.

FIG. **4** is a top view of a block diagram of a pole wheel positioned above a sensor according to an embodiment.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

Embodiments of the invention relate to magnetic sensor devices, such as Hall, giant magnetoresistive (GMR), and others. Embodiments of the invention integrate magnetic field concentrators and magnetic sensor devices, thereby increasing the magnetic sensitivity of the sensor devices. Various embodiments of the invention can be more readily understood by reference to FIGS. **1-4** and the following description. While the invention is not necessarily limited to the specifically depicted application(s), the invention will be better appreciated using a discussion of exemplary embodiments in specific contexts.

Referring to FIG. **1**, a sensor device **100** is depicted. Sensor device **100** comprises a die **102** on which additional sensor elements are mounted and/or formed. In one embodiment, sensor device **100** comprises first, second and third sensor elements **104**, **106** and **108** and first and second magnetic elements **110** and **112**.

In one embodiment, first and second sensor elements **104** and **106** comprise speed GMR sensor elements and third sensor element **108** comprises a direction GMR sensor element. In other embodiments, sensor device **100** comprises one or more Hall sensor elements, xMR sensor elements such as anisotropic magnetoresistive (AMR), tunneling magnetoresistive (TMR), colossal magnetoresistive (CMR), and GMR, and/or alternative configurations and combinations of sensor elements. Sensor elements **104**, **106** and **108** are U-shaped in the embodiment of FIG. **1** but can comprise meanders, strips and/or other configurations and combinations in other embodiments. In one embodiment, sensor elements **104** and **106** each comprise two equal parts, forming four resistors which can be connected in a Wheatstone bridge circuit. In another embodiment, only two resistors are used, and their values are compared (i.e., by injecting a current into each).

First and second magnetic elements **110** and **112** form a magnetic field concentrator in one embodiment, guiding magnetic flux perpendicularly to sensor elements **104**, **106** and **108**. This helps to ensure an ideal angle between magnetic field lines and sensor elements **104**, **106** and **108** and amplifies the flux density by about one order of magnitude. Thus, sensor device **100** comprises an integrated sensor and field concentrator. Magnetic elements **110** and **112** comprise a soft magnetic material, and the length of first and second magnetic elements **110** and **112** is at least slightly longer than first, second and third sensor elements **104**, **106** and **108** in one embodiment such that the field concentrating effects of first and second magnetic elements **110** and **112** extend along the entire length of sensor elements **104**, **106** and **108**. In one embodiment, sensor elements **104**, **106** and **108** are pre-magnetized perpendicular to their length such that current flows along the length. The magnetic flux is then concentrated by magnetic elements **110** and **112** perpendicularly to the current flow.

Another embodiment of sensor device **100** is depicted in FIG. **2**. In this embodiment, sensor device **100** comprises additional magnetic elements **114** and **116**. The addition of magnetic elements **114** and **116** provides further amplification of magnetic fields on sensor elements **104**, **106** and **108**.

In FIG. **3**, sensor device **100** of FIG. **1** is depicted in relation to a pole wheel **120**. Pole wheel **120** comprises a planar strip about 5 millimeters (mm) wide and 3 mm thick, and each individual pole **122** is about 5 mm long in one embodiment. The remanence of pole wheel **120** is about +/−0.25 T. Sensor device **100** is positioned about 8.5 mm above pole wheel **120**. In one embodiment, first and second magnetic elements **110** and **112** of sensor device **100** are about 1.2 mm wide and about 2 mm long. Each magnetic element **110** and **112** is about 10 micrometers (μm) to about 30 μm thick, such as about 20 μm in one embodiment. The gap between first and second magnetic elements **110** and **112** in which sensor element **108** is formed is about 20 μm in one embodiment, although it can also be about 10 μm or less in other embodiments. First and second sensor elements **104** and **106** are spaced apart by about 0.5 mm to about 5 mm or more, such as about 2.5 mm in one embodiment. Other spacings, sizes and configurations and combinations thereof can be used in other embodiments.

In the aforementioned embodiment, the in-plane flux density on sensor element **108** is about 3.65 mT, while sensor elements **104** and **106** are exposed to about 925 μT. In contrast, the flux density on sensor element **108** is only about 90 μT, and sensor elements **104** and **106** exposed to only about 125 μT, in an embodiment in which magnetic elements **110** and **112** are omitted. Magnetic elements **110** and **112** therefore provide amplification factors of about 40 in the flux density on sensor element **108**, and about 7 on sensor elements **104** and **106**, in one embodiment. Advantageously, sensor elements **104**, **106** and **108** and the gaps between magnetic elements **110** and **112** are as narrow as possible to provide the greatest increase in the amplification.

The addition of magnetic elements **110** and **112** to sensor device **100** also provides additional advantages. For example, if sensor device **100** is well-aligned with pole wheel **120**, there should be no y-component of the magnetic field acting on sensor elements **104**, **106**, and **108**. In fact, the magnetic characteristics of GMR sensor elements, such as sensor elements **104**, **106** and **108**, are altered if a y-component is superimposed on the x-component (the z-component vertical to die **102** is not relevant in this context). Because of position tolerances, die **102** and/or pole wheel **120** may be slightly tilted with respect to each other, as shown in FIG. **4**, and a magnetic field y-component acts on sensor elements **104**, **106** and **108**. This can introduce inaccuracies in the detection of the exact position of pole wheel **120**. If the tangential direction, t, of pole-wheel **120** is misaligned with the x-axis of sensor **100**, as shown at a, the decomposition of the magnetic field has a small y-component, which distorts the GMR characteristic.

In one embodiment of the invention, however, magnetic elements **110** and **112** have the additional beneficial effect of shunting this magnetic field y-component. Thus, only the x-component of the magnetic field is amplified by magnetic elements **110** and **112** while the y-component is suppressed. If the permeability of magnetic elements **110** and **112** is infinite, the flux-lines enter and leave perpendicular to the surface of magnetic elements **110** and **112**.

Although specific embodiments have been illustrated and described herein for purposes of description of an example embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations calculated to achieve the same purposes may be substituted for the specific embodiments shown and described without departing from the scope of the present invention. Those skilled in the art will readily appreciate that the invention may be implemented in a very wide variety of embodiments. This application is intended to cover any adaptations or variations of the various embodiments discussed herein, including the disclosure information in the attached appendices. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

The invention claimed is:

1. An integrated sensor and magnetic flux guide device comprising:

a sensor device comprising at least two xMR sensor elements, the at least two xMR sensor elements having a direction of shape anisotropy and being spaced apart from each other on a surface of a die to define a first gap; and

a magnetic flux guide comprising a soft magnetic material and being configured to reduce a magnetic field component along the direction of shape anisotropy, the magnetic flux guide being disposed in the first gap.

2. The device of claim **1**, wherein the first gap is in a range of about 0.5 mm to about 5 mm.

3. The device of claim **2**, wherein the first gap is about 2.5 mm.

4. The device of claim **1**, wherein the sensor device comprises first, second and third xMR sensor elements, the third sensor element disposed in the first gap defined by the first and second sensor elements, and wherein the magnetic flux guide comprises first and second magnetic elements, the first magnetic element disposed in the first gap between the first and third sensor elements and the second magnetic element disposed in the first gap between the first and second sensor elements.

5. The device of claim **4**, wherein the third sensor element is a direction xMR sensor element and the first and second sensor elements are differential xMR sensor elements.

6. The device of claim **4**, wherein the magnetic flux guide comprises at least one additional magnetic element.

7. The device of claim **1**, wherein the at least two sensor elements are selected from the group consisting of an anisotropic magnetoresistive (AMR) sensor element, a tunneling magnetoresistive (TMR) sensor element, a colossal magnetoresistive (CMR) sensor element, and a giant magnetoresistive (GMR) sensor element.

8. The device of claim **1**, wherein the device is configured to be spaced apart from an external magnetic field source by less than about 10 mm.

9. The device of claim **8**, wherein the device is configured to be spaced apart from the external magnetic field source by about 8.5 mm.

10. The device of claim **1**, wherein the magnetic flux guide is configured to shunt an undesirable portion of magnetic flux related to a misalignment of the device and an external magnetic field source.

11. A method comprising:

providing an integrated sensor and magnetic flux guide device, the sensor comprising first and second xMR sensor elements having a direction of shape anisotropy and being spaced apart by a gap of about 5 millimeters (mm) or less, and the magnetic flux guide comprising a soft magnetic material and being disposed in the gap;

exposing the device to a magnetic field; and

reducing a magnetic field component along the direction of shape anisotropy by the magnetic flux guide.

12. The method of claim **11**, further comprising shunting an undesirable portion of magnetic flux by the magnetic flux guide.

13. The method of claim **11**, wherein the device comprises at least one additional xMR sensor element and at least one additional magnetic flux guide.

14. The method of claim **11**, further comprising positioning the device relative to an external source of the magnetic field.

15. The method of claim **11**, wherein the providing comprises providing an integrated sensor and magnetic flux guide device, the sensor comprising first, second and third xMR sensor elements, the third xMR sensor element disposed in the gap, and the magnetic flux guide comprising first and second magnetic elements, the first magnetic element disposed between the first and third xMR sensor elements and the second magnetic element disposed between the third and second xMR sensor elements.

16. The method of claim **15**, wherein the magnetic flux guide comprises at least one additional magnetic element.

17. The method of claim **11**, wherein the first and second xMR sensor elements comprise differential xMR sensor elements and the third xMR sensor element comprises a direction xMR sensor element.

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